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GEORGE C. MARSHALL SPACE FLIGHT CENTER

HUNTSVILLE, ALABAMA

COMPUTER EVALUATION OF WINDS FROM METEOROLOGICAL ROCKETSONDE MEASUREMENTS

by

Bettye Anne Case

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ABSTRACT

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This report presents a method for determining wind and wind shear measurements, ground track, and fall rate of target from radar measured spherical position coordinates of a descending target. Due to errors inherent in the original measurements, it is considered that this method produces more representative values for altitude levels widely spaced with respect to time-sequenced data records than methods using interpolations. These computational procedures provide a means for excluding only time records determined erroneous in a given observation. The final tabulations give measurements that are averaged over approximately 500-meter layers, and centered at the designated altitude level.

Since data at altitude levels from 30 to 70 km are relatively sparse, the desire to use all the representative data in a given observation, even if it contained some obviously erroneous time records, led to the application of certain arbitrary mathematical standards for acceptable raw data. The theory involved in the data editing and evaluation procedures is discussed. The method is currently in use at Marshall Space Flight Center to evaluate data for a number of rocketsonde observations as well as for rocketsonde measurements used in flight evaluations. Author

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TERRESTRIAL ENVIRONMENT SECTION
AEROPHYSICS AND ASTROPHYSICS BRANCH
AEROBALLISTICS DIVISION

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DEFINITION OF SYMBOLS

N	The number of values concerned in a given calculation, corrected as deletions are made
R	Slant range; distance from point of tracking radar to target; meters unless otherwise stated
s	Standard deviation, $\left[\frac{\sum(X - \overline{X})^2}{N}\right]^{\frac{1}{2}}$
S 250n	Wind shear, computed over layer of size indicated by 250n, where n is an integer 2, 4, . . . , and based on scalar wind velocity, W
S_{S-N} 250n	Meridional component wind shear, computed over layer of size indicated by 250n, and based on component wind velocity, W_{S-N}
S_{W-E} 250n	Zonal component wind shear, computed over layer of size indicated by 250n, and based on component wind velocity, W_{W-E}
S_X 250n	Pitch component wind shear, computed over layers of size indicated by 250n, and based on component wind velocity, W_X
S_Z 250n	Yaw component wind shear, computed over layers of size indicated by 250n, and based on component wind velocity, W_Z
t	A time point under consideration
V_Y	Rate of fall of target; meters per second
W	Scalar wind velocity based on distance traveled by target in plane tangent to earth at position of radar; meters per second

DEFINITION OF SYMBOLS (Cont.)

W_{S-N}	Meridional or south to north positive component of wind velocity in plane tangent to earth at position of radar; meters per second
W_{W-E}	Zonal or west to east positive component of wind velocity in plane tangent to earth at position of radar; meters per second
W_X	Pitch component of wind velocity in plane tangent to earth at position of radar, referenced to the vehicle flight azimuth and taken parallel to the vehicle standard flight path, from tail to head positive; meters per second
W_Z	Yaw component of wind velocity in plane tangent to earth at position of radar, referenced to the vehicle flight azimuth and taken perpendicular to the vehicle standard flight path, from left to right positive; meters per second
WD	Direction from which the wind is blowing, positive clockwise from North; degrees
X	Cartesian referenced zonal (west - east) position coordinate where origin is at radar, in plane tangent to earth at radar; meters, positive toward east
Y	Height of target above plane tangent to earth at radar; meters
Z	Cartesian referenced meridional (south - north) position coordinate where origin is at radar, in plane tangent to earth at radar; meters, positive toward north
α	Flight azimuth of vehicle to which wind components are to be referenced, clockwise from North; degrees
θ	Elevation angle; the angle between plane tangent to earth at radar and line from radar to target; degrees positive upward from tangent plane

DEFINITION OF SYMBOLS (Cont.)

ψ	Azimuth angle; the angle between true north and projected line from radar to target in plane tangent to earth at target; degrees positive from North clockwise

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SUMMARY

This report presents a method for determining wind and wind shear measurements, ground track, and fall rate of target from radar measured spherical position coordinates of a descending target. Due to errors inherent in the original measurements, it is considered that this method produces more representative values for altitude levels widely spaced with respect to time-sequenced data records than methods using interpolations. These computational procedures provide a means for excluding only time records determined erroneous in a given observation. The final tabulations give measurements that are averaged over approximately 500-meter layers, and centered at the designated altitude level.

Since data at altitude levels from 30 to 70 km are relatively sparse, the desire to use all the representative data in a given observation, even if it contained some obviously erroneous time records, led to the application of certain arbitrary mathematical standards for acceptable raw data. The theory involved in the data editing and evaluation procedures is discussed. The method is currently in use at Marshall Space Flight Center to evaluate data for a number of rocketsonde observations as well as for rocketsonde measurements used in flight evaluations.

SECTION I. INTRODUCTION

Rocketsonde observations are regularly made to support the evaluation of major space vehicle flights and on a routine basis to accumulate better information about the winds at the concerned altitude levels (up to about 70 km) (Ref. 4). The purpose of this report is to present a method for evaluation of these measurements which uses all the data within an observation except that which is suspected wrong due to instrumental or other errors. The resulting parameters determined by the methods described in this paper may be considered average or representative of the true values near the specified altitude point. Observations evaluated by this program are presented in height-sequenced tabular form and graphs are made by computer procedures for certain parameters. A tape is kept for record and future investigations of the basic measurements.

Numerous people contributed to this report, and aid at many stages is acknowledged from W. W. Vaughan, O. E. Smith, J. R. Scoggins, and J. W. Smith of this branch, and Frank Herring of the Computation Division.

SECTION II. NATURE OF MEASUREMENTS

A. METHOD OF OBSERVATION

Radar tracking data, consisting of TAER (time, azimuth, elevation, and slant range) measurements from rocketsonde targets, present difficulties in devising evaluation techniques due to many error-producing factors of random and biased natures inherent in the physical operation and nature of measurement. A rocket is fired and a target is released. This target is then radar tracked to yield spherical position coordinates: the distance from the radar to the target (range, R); the angle made by this vector (R) with the tangent ground plane (elevation, θ); and the angle formed by the projection of this vector (R) on the ground plane with true north (azimuth, ψ). These measurements are time sequenced at equal intervals, usually spaced from 0.1 sec to 1 sec apart.

Currently, the Atlantic Missile Range uses an ARCAS or LOKI Rocket (depending on availability of equipment and desired altitude) to obtain the data that are available to Marshall Space Flight Center. An FPS-16 or another radar system is used to track a parachute, Robin sphere, or chaff target. When the more accurate radar systems are used, such as the FPS-16, the data obviously contain fewer random and biased instrumental errors. A Robin sphere or parachute used as a target falls too rapidly at high altitudes (approximately >70 km) for measurement of desired relatively closely spaced position coordinates; the high rate of fall makes the target less responsive to wind changes. A chaff target, being of low density, overcomes this disadvantage of the Robin sphere or parachute, but frequently disperses in such a manner that the radar shifts in the tracking from one to another of the concentrations of chaff.

B. BASIC DATA

The basic data arrives at Marshall Space Flight Center on magnetic tapes. The spherical position coordinates of the target are given at equal time increments, with test identification data. The units for all observations are not consistent, but must be converted to seconds, degrees, and meters before use in the equations of the program described herein.

SECTION III. DATA REDUCTION TECHNIQUES

A. PROCEDURE FOR PRE-EDITING BASIC DATA

After conversion of the basic data to the proper units, differences between successive time record values of slant range are considered. If the difference is greater than 500 m, the next two successive values are tested. If this difference also is greater than 500 m, the middle time record is deleted, and testing continues between the first and third values. If the difference between the second and third ranges is not also greater than 500 m, all points are kept and the testing continues with the third and fourth ranges. This same procedure is applied to azimuth and elevation angles, choosing 5° as the criterion of difference. Thus, values which seem obviously not to be accounted for by either trend or orderly random variation are rapidly deleted before any evaluation proceeds.

B. DETERMINATION AND TESTING OF TIME-SEQUENCED POSITION COORDINATES

After deletion of time records as necessary in the pre-editing procedure, time-sequenced Cartesian position coordinates are computed from each set of spherical coordinates:

$$
\begin{aligned}
Y &= R \sin\theta \\
X &= R \cos\theta \sin\psi \\
Z &= R \cos\theta \cos\psi
\end{aligned}
\tag{1}
$$

Altitude layers for data records of approximately 500 m are selected, each overlapping the next by approximately 250 m. A given 500 m altitude layer has as its first time record the data point immediately preceding the top of the layer and as its last time record the data point immediately following the bottom of the layer. Data computed from this layer are subsequently attributed to a multiple of 250 m which is near its midpoint.

Each group of X, Y, and Z position coordinates corresponding to an altitude layer is separately tested by a procedure adapted from Chauvenet's criterion for rejection of stray or erroneous values. If the group of position coordinates under consideration were selected from a normal distribution in a random manner, this test would reject those values having a probability of occurrence of less than $\frac{1}{2}$N, where N is the number of points in the group (Refs. 1, 2). Though this normality criterion can rarely be met with a group of position coordinates, the procedure described below is a convenient means of mathematically determining an arbitrary limit to the amount of allowable variation. In editing FPS-16 radar tracked spherical balloon data Scoggins (Ref. 3) uses a fixed three times the RMS error as the allowable deviation from the arithmetic mean for the midpoint of a group of nine points, moving along the time sequenced data one point at a time with testing centered about each point. This procedure is applied to each of the observed spherical position coordinates. The procedure adapted from Chauvenet's criterion and applied in this paper to each of the Cartesian position coordinates uses a variable multiple of the RMS error within a group of points, size depending on the number of points, as the allowable deviation from the arithmetic mean for any point within the group of values.

For an example, consider a group of N ($N \geq 3$) position coordinates, X. The arithmetic mean and standard deviation of these values are determined as follows:

$$\overline{X} = \frac{\Sigma X}{N}$$

$$s = \left[\frac{\Sigma(X - \overline{X})^2}{N}\right]^{\frac{1}{2}} \tag{2}$$

The reduced deviation of each coordinate from this mean is computed (Ref. 6):

$$d_i = \frac{(X_i - \overline{X})}{s} \tag{3}$$

Each of these deviations is compared to F (N), where F (N) is determined from the following polynomial in ln N fitted by Smith and Cloud to the tabular values given by Brooks and Carruthers for Chauvenet's criterion (Refs. 1 and 5):

$$F(N) = 0.67706000 + 0.74397726(\ln N) - 0.11070440(\ln N)^2 + 0.01571102(\ln N)^3 - 0.00126799(\ln N)^4 + 0.00004178(\ln N)^5 \tag{4}$$

Where d_i exceeds F (N), time record t_i is deleted from consideration in this layer.

This test is repeated until the test will delete no further time records from the group of points. The averaging and testing procedure is then applied to Z position coordinates and to Y position coordinates. If the number of time records remaining in the layer is greater than or equal to three, evaluation may continue as described in Paragraph D below.

C. PROVISIONS FOR INSUFFICIENT OR MISSING ALTITUDE LAYERS

Difficulty arises when a chosen altitude layer has less than three time records. If this occurs in the original selection of an altitude layer four time records after the last altitude point in the layer are tested one at a time to see if they should fall in the layer. If any of these time records test in the layer, additional time records are tested until the true bottom of the layer is reached. If the layer now contains at least three time records, it is treated as described above in B. If it does not, the next lower altitude layer is chosen. If three successive altitude layers contain insufficient records for evaluation, a break is accepted in the data and evaluation begins again as for a new test in the same manner as from the beginning of the observation. If three or less successive layers contain insufficient records, followed by a complete layer, linear interpolation is used to complete tabular values as described in Paragraph D.

Difficulty may further arise when a pre-edited layer has three or more time records but by Chauvenet's test it is reduced to less than three time records. In that case, the next layers are considered and a decision to interpolate or to show a break in the data is made on the same basis as in the above paragraph.

D. DETERMINATION OF ALTITUDE-SEQUENCED VALUES

When the time records to be kept for a given altitude layer are determined, the target rate of fall and directional wind components are computed for all except the first and last time points in each layer:

$$V_Y = \frac{Y_{i+1} - Y_{i-1}}{t_{i+1} - t_{i-1}}$$

$$W_{W-E} = \frac{X_{i+1} - X_{i-1}}{t_{i+1} - t_{i-1}} \qquad (5)$$

$$W_{S-N} = \frac{Z_{i+1} - Z_{i-1}}{t_{i+1} - t_{i-1}}$$

The arithmetic mean of each set of values is taken, and is considered the value at the altitude 250 m below the multiple of 250 m which was the top of the layer (i.e., it is attributed to the midpoint of the layer).

$$V_{Y_{250}} = \frac{\Sigma V_Y}{N-2}$$

$$W_{W-E_{250}} = \frac{\Sigma W_{W-E}}{N-2} \qquad (6)$$

$$W_{S-N_{250}} = \frac{\Sigma W_{S-N}}{N-2}$$

Using these mean values so attributed for W_{W-E} and W_{S-N}, wind speed and direction and vehicle referenced wind components are computed:

$$W = (W^2_{W-E} + W^2_{S-N})^{\frac{1}{2}} \tag{7}$$

$$\text{WD: At each time point, } Q = \tan^{-1}\left|\frac{W_{W-E}}{W_{S-N}}\right| \tag{8}$$

Using the signs of the components as follows, correct this value as to quadrant for the proper sign convention:

both positive: $WD = 180° + Q$

both negative: $WD = Q$

$W_{W-E}+$, $W_{S-N}-$: $WD = 360° - Q$

$W_{W-E}-$, $W_{S-N}+$: $WD = 180° - Q$

$$W_X = W_{W-E}\cos(\alpha - 90°) - W_{S-N}\sin(\alpha - 90°) \tag{9}$$

$$W_Z = -W_{W-E}\sin(\alpha - 90°) - W_{S-N}\cos(\alpha - 90°) \tag{10}$$

α = original flight direction of vehicle

After linear interpolations have been performed on V_Y, W_{W-E}, and W_{S-N}, when empty layers do not exceed three, and after W, WD, W_X and W_Z are computed for every altitude level under consideration, wind shear values may be computed over the layer thickness desired. The wind shear values are attributed to the top of the layer. Thus, zonal, or west-east referenced, 500 m shear value at altitude level, i, is computed:

$$S_{W-E_i} = \frac{W_{W-E_i} - W_{W-E_{(i-500)}}}{500} \tag{11}$$

Shears corresponding to each wind speed and wind speed component may likewise be computed and are shown in the print-out as described in Section IV.

SECTION IV. METHODS AND FORMS OF PRESENTATION OF COMPUTER RESULTS

The basic computer print-out as now programmed consists of two tables of altitude-sequenced data, at even 250 m intervals, preceded by identification in the form of test number and date. Layers for which data are based on interpolation are indicated by a code identification which consists of the addition of 100, 000 to the reference altitude. The capacity is also available for time-sequenced print-out of X, Y, and Z position coordinates, by 500 m altitude layers.

TABLE I

Test Number Date of Test

Y	VY	W(W - E)	W(S - N)	WX	WZ	W	WD	X	Z
M	M/SEC	M/SEC	M/SEC	M/SEC	M/SEC	M/SEC	DEGREES	M	M

TABLE II

Test Number Date of Test

Y	S	S(W - E)	S(S - N)	SX	SZ	S	S(W - E)	S(S - N)	SX	SZ
M	500M	500M	500M	500M	500M	1000M	1000M	1000M	1000M	1000M

In addition to the print-out, results are presented graphically by automatic altitude-sequenced plots of W and WD values. A magnetic tape is kept of all evaluated rocketsonde observations, referenced by date and test number. Altitude-sequenced rate of fall, wind speed and wind direction are recorded.

SECTION V. CONCLUSIONS AND RECOMMENDATIONS

Due to errors inherent in rocketsonde observations which cannot be mathematically determined or accounted for, the results of any evaluation program must be considered only an indication of the physical wind flow situation at the indicated time and altitude. This program uses all of the time records of data which are not determined to be in error for the computation of altitude-sequenced values. There is sufficient flexibility to handle a certain amount of instrumental error (such as the changing of the radar tracking from one concentration of chaff to another) by means of either eliminating a limited number of erroneous time records or by interpolating over one to three 250 m altitude intervals for which time records were determined erroneous or were completely missing from the observation. These adjustments for and adaptations to bad data are handled by the computer. Furthermore, capacity is retained in the making of the continuous magnetic tape of rocketsonde evaluations to omit an entire rocketsonde observation considered to be based on such bad data as to contribute no reliable information, or a first or last portion of an observation when the remainder appears reliable. This tape will be used for future statistical investigations of winds at the altitudes of interest. A future paper from this branch will present the results of evaluation of a large number of rocketsonde observations.

Use of the FPS-16 radar in tracking yields consistently more reliable basic measurements, and its use is recommended whenever feasible.

Resulting winds from this evaluation are in good agreement with rawinsonde measurements in the altitude layers for which both measurements are available.

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